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(54) **LOW-LOSS CRYOGENIC FLUID SUPPLY SYSTEM AND METHOD**

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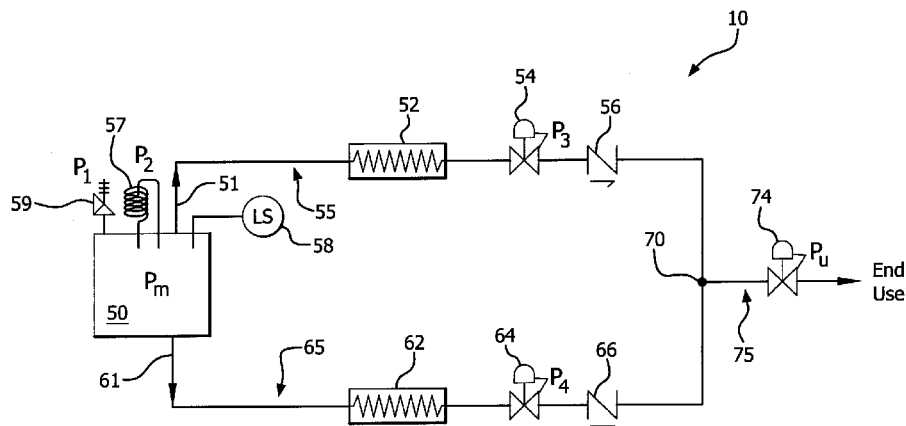
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(57) **ABSTRACT**

A low-loss cryogenic fluid supply system having at least one main cryogenic fluid tank and a backup cryogenic fluid tank each having a vent set to a first pressure P1 and a pressure build circuit set to a second pressure P2, a main tank gas supply line configured to supply gas to a junction at a third pressure P3, a main tank liquid supply line configured to supply gas to the junction at a fourth pressure P4, a backup tank liquid supply line configured to supply gas to the junction at a fifth pressure P5, a backup tank backpressure regulator configured to supply gas to a point upstream to the main tank gas supply line at a sixth pressure P6, and an outlet supply line configured to supply gas from the junction at an end use pressure Pu, where P1>P3≥P2, P1≥P6>P2, P6≥P3>P4>P5>Pu.

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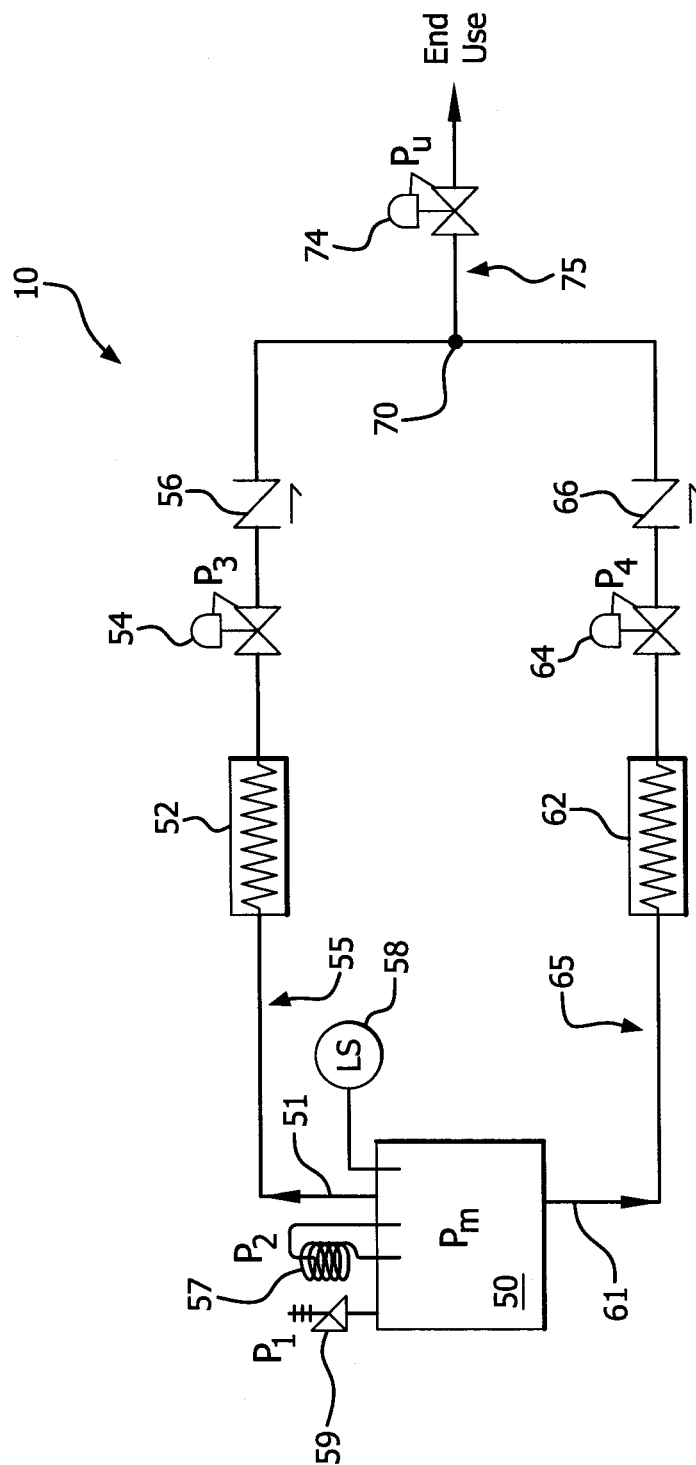


FIG. 1

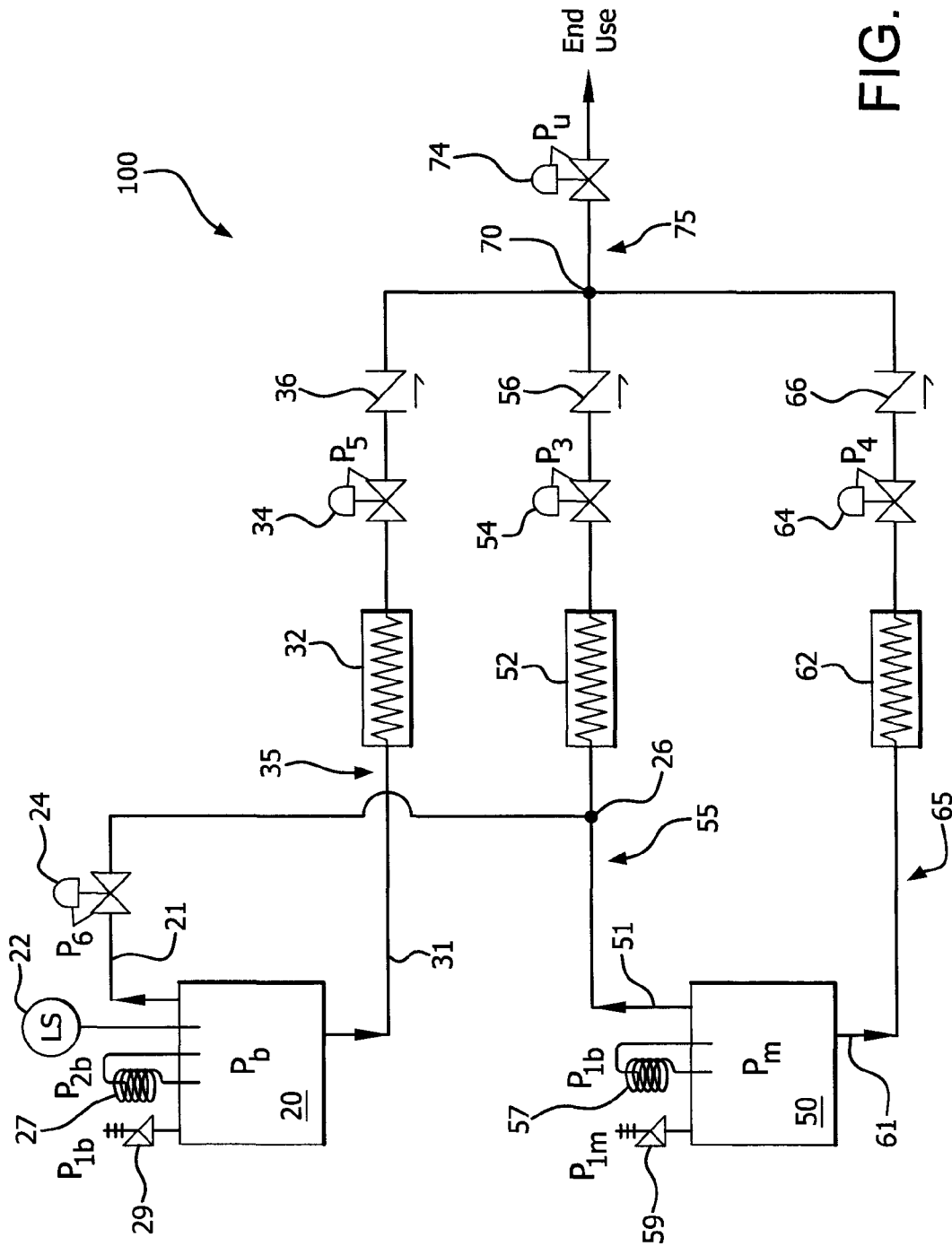


FIG. 2

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LOW-LOSS CRYOGENIC FLUID SUPPLY SYSTEM AND METHOD

BACKGROUND

This application relates to a cryogenic fluid supply system with reduced or minimized loss of cryogenic fluid. More specifically, this application relates to a cryogenic fluid supply system of the type commonly use to supply medical oxygen on an intermittent basis in which the loss of cryogenic fluid is significantly reduced from the losses normally experienced by a conventional system.

In a conventional cryogenic fluid supply system, cryogen is supplied from a tank containing liquid cryogen, as well as some vapor cryogen in the headspace above the liquid. Typically, liquid is withdrawn from the bottom of the tank and vaporized for an end use. For example, conventional systems like this are often used for supplying medical oxygen from a liquid oxygen tank or dewar. However, because many uses are intermittent, a conventional system may experience significant losses of cryogen when the end use is temporarily stopped. Specifically, any liquid cryogen remaining in the supply lines and vaporizer takes on heat from the ambient environment, and as the resultant pressure increase pushes some of the remaining liquid back into the tank, some of that heat is also carried back into the tank. This causes the tank to increase in pressure. Ultimately, the tank needs to vent to relieve some of the excess pressure buildup, resulting in loss of cryogen. An object of the presently described system and method is to overcome this problem with conventional systems.

SUMMARY

An embodiment of a low-loss cryogenic fluid supply system includes at least one main cryogenic fluid tank and may include a backup cryogenic fluid tank. The main tank has a gas outlet, a liquid outlet, a pressure build circuit, and a vent, the vent being configured to exhaust pressure from the main tank at a first pressure P1, the pressure build circuit being configured to build pressure in the main tank to a second pressure P2 less than the first pressure P1. The backup tank has a gas outlet, a liquid outlet, a pressure build circuit, and a vent, the vent being configured to exhaust pressure from the backup tank at the first pressure P1, the pressure build circuit being configured to build pressure in the backup tank to the second pressure P2. A gas supply line is connected to the main tank gas outlet and has a pressure regulator configured to supply gas to a junction at a third pressure P3 greater than or equal to the second pressure P2 and less than the first pressure P1. A main liquid supply line has a heat exchanger to vaporize liquid from the main tank liquid outlet and a pressure regulator configured to supply the vaporized liquid to the junction at a fourth pressure P4 less than the third pressure P3. A backup liquid supply line has a heat exchanger to vaporize liquid from the backup tank liquid outlet and a pressure regulator configured to supply the vaporized liquid to the junction at a fifth pressure P5 less than the fourth pressure P4. A backup tank backpressure regulator is configured to enable gas flow from the backup tank gas outlet to a point in the gas supply line upstream of the gas supply line pressure regulator at a sixth pressure P6 greater than the third pressure P3 and less than the first pressure P1. An outlet supply line is configured to flow gas from the junction and having a point-of-use pressure regulator configured to supply gas at an end use pressure Pu than the fifth pressure P5.

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In one aspect of the system, the backup tank has a low level switch. In another aspect of the system, a heat exchanger is positioned in gas supply line upstream of the gas supply line pressure regulator. In yet another aspect of the system, the cryogen is oxygen. In a further aspect of the system, the cryogen is nitrogen.

An embodiment of method of minimizing the loss of cryogenic fluid in a cryogenic fluid supply system utilizes at least one main cryogenic fluid tank having an internal pressure and a backup cryogenic fluid tank having an internal pressure. The method includes venting the main tank when the main tank internal pressure is greater than a first pressure P1, vaporizing cryogenic liquid and returning the vaporized liquid to the at least one main tank when the main tank internal pressure is less than a second pressure P2, wherein P2 is less than P1, venting the backup tank when the backup tank internal pressure is greater than the first pressure P1, and vaporizing cryogenic liquid and returning the vaporized liquid to the backup tank when the backup tank internal pressure is less than the second pressure P2. Cryogenic gas is supplied from the main tank to a junction at a pressure less than or equal to a third pressure P3, wherein P3 is less than P2. Cryogenic liquid is flowed from the main tank, vaporized, and supplied to the junction at a pressure less than or equal to a fourth pressure P4 when the pressure at the junction falls below P4. Cryogenic liquid is flowed from the backup tank, vaporized, and supplied to the junction at a pressure less than or equal to a fifth pressure P5 when the pressure at the junction falls below P5. Cryogenic gas is flowed from the backup tank when the backup tank internal pressure is greater than a sixth pressure P6 and greater than the main tank internal pressure, wherein P6 is greater than P3 and less than P1. Cryogenic gas is supplied from the junction to a point of use at an end use pressure Pu less than the fifth pressure P5.

In one aspect, the method further includes providing an alarm signal when a level of cryogenic liquid in the backup tank falls below a preset level. In another aspect, the method further includes warming the cryogenic gas in the main gas supply line. In yet another aspect, the cryogen used in the method is oxygen. In a further aspect, the cryogen used in the method is nitrogen.

Another embodiment of a low-loss cryogenic fluid supply system includes at least one main cryogenic fluid tank, the main tank having a gas outlet, a liquid outlet, a pressure build circuit, and a vent, the vent being configured to exhaust pressure from the main tank at a first pressure P1, the pressure build circuit being configured to build pressure in the main tank to a second pressure P2 less than the first pressure P1. A gas supply line is connected to the main tank gas outlet and having a pressure regulator configured to supply gas to a junction at a third pressure P3 greater than or equal to the second pressure P2 and less than the first pressure P1. A main liquid supply line has a heat exchanger to vaporize liquid from the main tank liquid outlet and a pressure regulator configured to supply the vaporized liquid to the junction at a fourth pressure P4 less than the third pressure P3. An outlet supply line is configured to flow gas from the junction and having a point-of-use pressure regulator configured to supply gas to a point of use at a use pressure Pu less than the fourth pressure P4.

In one aspect, the system further includes a low level switch in the main tank.

In another aspect, the system further includes a backup cryogenic fluid tank, the backup tank having a gas outlet, a liquid outlet, a pressure build circuit, and a vent, the vent being configured to exhaust pressure from the backup tank at the first pressure P1, the pressure build circuit being config-

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ured to build pressure in the backup tank to the second pressure P2. A backup liquid supply line has a heat exchanger to vaporize liquid from the backup tank liquid outlet and a pressure regulator configured to supply the vaporized liquid to the junction at a fifth pressure P5 less than the fourth pressure P4.

In still another aspect, system further includes a backup tank backpressure regulator configured to enable gas flow from the backup tank gas outlet to a point in the gas supply line upstream of the gas supply line pressure regulator at a sixth pressure P6 greater than the third pressure P3 and less than the first pressure P1.

In yet another aspect, the system further includes a low level switch in the backup tank.

The various aspects of the system disclosed herein can be used alone or in combinations with each other.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an embodiment of a low-loss cryogenic fluid supply system.

FIG. 2 is a schematic view of another embodiment of a low-loss cryogenic fluid supply system.

DETAILED DESCRIPTION

FIG. 1 shows an embodiment of a low-loss cryogenic fluid supply system 10. Although one of the commercially significant uses for such a system 10 is to supply medical oxygen, such a system 10 can also be used to supply any other fluid that can be transported, stored, and delivered in cryogenic form, including but not limited to nitrogen, argon, and helium. The system 10 includes at least one main cryogenic fluid tank 50. The system 10 can perform equally well with one, two, or three or more main cryogenic fluid tanks 50, so that the number of tanks 50 can be adjusted depending on the particular installation and space requirements.

The main tank 50 is operated at an internal pressure Pm. The maximum main tank internal pressure is set at a first pressure P1, by a vent valve 59. A pressure build circuit 57, as known in the art, is operable to increase the main tank internal pressure when it falls below a second pressure P2. For typical cryogenic fluid installations, the first (vent) pressure P1 is set to a pressure from about 200 PSIG to about 275 PSIG, and is preferably about 250 PSIG, while the second (pressure build circuit) pressure P2 is set to a pressure from about 140 PSIG to about 200 PSIG, and is preferably about 160 PSIG. When the main tank 50 is not supplying any cryogenic fluid, heat leak typically causes a slow increase in pressure, and if Pm reaches P1, the vent valve 59 will open to relieve pressure from the main tank 50. When the main tank 50 is supplying cryogenic fluid at a high flow rate, Pm may drop below P2, at which point the pressure build circuit 57 will become and remain activated until Pm reaches P2.

The main tank 50 includes a gas outlet 51 for supplying cryogenic gas or vapor, and a liquid outlet 61 (often in the form of a diptube) for supplying cryogenic liquid.

A gas supply line 55 is connected to the main tank gas outlet 51. A heat exchanger 52 may be positioned downstream of the junction 26 to warm the cryogenic gas flowing from the tank 50 to a temperature suitable for use. A pressure regulator 54 in the gas supply line 55 reduces the pressure to a third pressure P3, which is supplied to a junction 70. The third pressure P3 is greater than or equal to the second (pressure build) pressure P2. The third pressure P3 is set to a pressure from about 140 PSIG to about 190 PSIG, and is preferably about 160 PSIG. A check valve 56 may be positioned down-

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stream of the pressure regulator 54 and upstream of the junction 70 to prevent backflow into the gas supply line 55.

A main liquid supply line 65 is connected to the main tank liquid outlet 61. A heat exchanger 62 is positioned downstream of the liquid outlet 61 to vaporize the cryogenic liquid and warm the resultant cryogenic gas or vapor. A pressure regulator 64 in the main liquid supply line 65 reduces the gas pressure to a fourth pressure P4, which is supplied to the junction 70 when needed. The fourth (main liquid supply) pressure P4 is less than the third (gas supply) pressure P3, so that gas is supplied via the main liquid supply line 65 only when the gas supply line 55 has insufficient pressure to meet the end use flow requirements. A check valve 66 may be positioned downstream of the pressure regulator 64 and upstream of the junction 70 to prevent backflow into the main liquid supply line 65. The fourth pressure P4 is set to a pressure from about 120 PSIG to about 160 PSIG, and is preferably about 140 PSIG.

An outlet supply line 75 is connected to the junction 70 and includes a point-of-use pressure regulator 74 to reduce the pressure of the gas to an end use pressure Pu suitable for end use. The end use pressure Pu is less than the fourth (main liquid supply) pressure P4. The end use is set to a pressure from about 25 PSIG to about 100 PSIG, and is preferably about 65 PSIG.

In sum, the relationship of the pressure setpoints described above in the system 10 is as follows: (a) $P1 \geq Pm$, (b) $P1 > P3 \geq P2$, and (c) $P3 > P4 > Pu$.

The system 10 may further include a low level switch 58 in the main tank 50 to alert an operator when the supply of cryogenic fluid is running low.

The system 10 may further include a heat exchanger 52 in gas supply line 55 upstream of the gas supply line pressure regulator 54 to warm the cryogenic gas to a temperature suitable for end use.

In use, the system 10 minimizes the loss of cryogenic fluid by operating in the following sequence. First, only if the system 10 is not in use for an extended period of time will the main tank pressure Pm increase sufficiently by natural heat leak to necessitate venting of cryogenic gas via the vent 59.

Next, when gas is demanded at the point of use, the system 10 draws only cryogenic gas from the main tank 50 via the gas supply line 55, as long as the main tank 50 is generating enough cryogenic gas. Preferably, this gas is warmed by heat exchanger 52 to a temperature suitable for end use. This gas is regulated to a pressure less than or equal to the third pressure P3 by the pressure regulator 54. If the main tank 50 is not generating enough gas through natural heat leak, the pressure build circuit 57 operates to add heat to the main tank 50, thereby increasing and maintaining the pressure Pm in the main tank 50. If the end use is stopped while only gas is being drawn from the main tank 50, the cryogen gas remaining in the gas supply line 55 will take on some heat, but far less than a liquid cryogen would take on, and very little of this heat will be returned to the main tank 50. Therefore, the resultant loss of cryogen is maintained at a very low level during such a temporary shutdown of end use demand.

Next, only if end use demand exceeds the ability of the main tank pressure build circuit 57 to maintain the main tank pressure Pm, the system 10 draws cryogenic liquid from the main tank 50 via the main liquid supply line 65 and vaporizes that liquid in the heat exchanger 62. When the main tank pressure Pm drops, the supply pressure to the pressure regulator 54 will drop sufficiently that the pressure at the junction 70 falls below the third pressure P3 to the fourth pressure P4, thereby enabling flow through the main liquid supply line 65. Flow will continue through the main liquid supply line 65 as

long as the pressure at the junction **70** remains at or below the fourth pressure **P4**, which is the output of the pressure regulator **64**.

By lessening the demand on the gas supply line **55**, the pressure build circuit **57** is typically able to restore the main tank pressure **Pm** sufficiently to enable the main liquid supply line flow to cease, when the main tank **50** still contains an appreciable amount of cryogenic liquid. However, when the liquid level in the main tank **50** is running low, the pressure build circuit **57** will not be able to generate sufficient pressure to return to gas-only supply, and liquid will continue to be drawn from the liquid outlet **61** as the pressure at the junction **70** remains at or below the fourth pressure **P4**.

If the end use is stopped while both gas and liquid are being drawn from the main tank **50**, some additional heat will be returned to the main tank **50** from the liquid taking on heat in the main liquid supply line **65**. However, because of the configuration of the system **10**, liquid was being drawn because the main tank pressure **Pm** was too low, and specifically was less than the setpoint **P2** of the pressure build circuit **57**. Therefore, any heat returned to the main tank **50**, and the resultant pressure increase in the main tank **50**, will merely restore the main tank pressure **Pm** to the desired range (i.e., greater than or equal to **P2** and less than or equal to **P1**) and will likely result in no, or minimal, venting or loss of cryogen.

Finally, when the level in the backup tank **20** reaches a point indicating that the tank **50** needs to be refilled, the level switch **58** alarms. By this point, the pressure build circuit **57** will be running continuously and cryogen will be flowing through both the gas supply line **55** and the main liquid supply line **65** in order to meet the end use demand.

FIG. 2 shows an embodiment of a low-loss cryogenic fluid supply system **100**. The system **100** includes at least one main cryogenic fluid tank **50** and a backup cryogenic fluid tank **20**. The system **100** can perform equally well with one, two, or three or more main cryogenic fluid tanks **50**, so that the number of tanks **50** can be adjusted depending on the particular installation and space requirements. Also, more than one backup tank **20** may be used to provided additional backup volume, although typically one backup tank **20** is sufficient.

The main tank **50** is operated at an internal pressure **Pm**. The maximum main tank internal pressure is set at a first pressure **P1m**, by a vent valve **59**. A pressure build circuit **57**, as known in the art, is operable to increase the main tank internal pressure when it falls below a second pressure **P2m**. For typical cryogenic fluid installations, the first (vent) pressure **P1m** is set to a pressure from about 200 PSIG to about 275 PSIG, and is preferably about 250 PSIG, while the second (pressure build circuit) pressure **P2m** is set to a pressure from about 140 PSIG to about 200 PSIG, and is preferably about 160 PSIG. When the main tank **50** is not supplying any cryogenic fluid, heat leak typically causes a slow increase in pressure, and if **Pm** reaches **P1m**, the vent valve **59** will open to relieve pressure from the main tank **50**. When the main tank **50** is supplying cryogenic fluid at a high flow rate, **Pm** may drop below **P2m**, at which point the pressure build circuit **57** will become and remain activated until **Pm** reaches **P2m**.

The main tank **50** includes a gas outlet **51** for supplying cryogenic gas or vapor, and a liquid outlet **61** (often in the form of a diptube) for supplying cryogenic liquid.

The backup tank **20** is operated at an internal pressure **Pb**. The maximum backup tank internal pressure is set at a first pressure **P1b**, by a vent valve **29**. A pressure build circuit **27**, as known in the art, is operable to increase the main tank internal pressure when it falls below a second pressure **P2b**. When the backup tank **20** is not supplying any cryogenic fluid, heat leak typically causes a slow increase in pressure,

and if **Pb** reaches **P1b**, the vent valve **29** will open to relieve pressure from the backup tank **20**. When the backup tank **20** is supplying cryogenic fluid at a high flow rate, **Pb** may drop below **P2b**, at which point the pressure build circuit **27** will become and remain activated until **Pb** reaches **P2b**.

Usually, **P1b** will be approximately equal to **P1m**, and **P2b** will be approximately equal to **P2m**; therefore, **P1b** and **P1m** are sometimes referred to generically herein as **P1**, and **P2b** and **P2m** are sometimes referred to generically herein as **P2**.

The backup tank **20** includes a gas outlet **21** and a backup tank backpressure regulator **24** that enables gas flow from the gas outlet **21** at a sixth pressure **P6**, wherein **P6** is greater than the second pressure **P2** and less than the first pressure **P1**. The backpressure regulator **24** helps to decrease loss of cryogenic fluid by venting from the backup tank **20**, instead making cryogenic gas available for use via the gas outlet **21** when the backup tank internal pressure **Pb** is above the pressure build circuit pressure **P2** but below the vent pressure **P1**. The backpressure regulator pressure **P6** is set to a pressure from about 160 PSIG to about 225 PSIG, and is preferably about 200 PSIG.

A gas supply line **55** is connected to the main tank gas outlet **51**, and is also connected to the downstream side of the backup tank backpressure regulator **24** at a junction **26**. A heat exchanger **52** may be positioned downstream of the junction **26** to warm the cryogenic gas flowing from the tanks **20** and **50** to a temperature suitable for use. A pressure regulator **54** in the gas supply line **55** reduces the pressure to a third pressure **P3**, which is supplied to a junction **70**. The third pressure **P3** is greater than or equal to the second (pressure build) pressure **P2** and less than the sixth (backup tank backpressure regulator) pressure **P6**. The third pressure **P3** is set to a pressure from about 140 PSIG to about 190 PSIG, and is preferably about 160 PSIG. A check valve **56** may be positioned downstream of the pressure regulator **54** and upstream of the junction **70** to prevent backflow into the gas supply line **55**.

A main liquid supply line **65** is connected to the main tank liquid outlet **61**. A heat exchanger **62** is positioned downstream of the liquid outlet **61** to vaporize the cryogenic liquid and warm the resultant cryogenic gas or vapor. A pressure regulator **64** in the main liquid supply line **65** reduces the gas pressure to a fourth pressure **P4**, which is supplied to the junction **70** when needed. The fourth (main liquid supply) pressure **P4** is less than the third (gas supply) pressure **P3**, so that gas is supplied via the main liquid supply line **65** only when the gas supply line **55** has insufficient pressure to meet the end use flow requirements. A check valve **66** may be positioned downstream of the pressure regulator **64** and upstream of the junction **70** to prevent backflow into the main liquid supply line **65**. The fourth pressure **P4** is set to a pressure from about 120 PSIG to about 160 PSIG, and is preferably about 140 PSIG.

A backup liquid supply line **25** is connected to the backup tank liquid outlet **31**. A heat exchanger **32** is positioned downstream of the liquid outlet **31** to vaporize the cryogenic liquid and warm the resultant cryogenic gas or vapor. A pressure regulator **34** in the backup liquid supply line **25** reduces the gas pressure to a fifth pressure **P5**, which is supplied to the junction **70** when needed. The fifth (backup liquid supply) pressure **P5** is less than the fourth (main liquid supply) pressure **P4**, so that gas is supplied via the backup liquid supply line **25** only when the main tank, via the gas supply line **55** and the main liquid supply line **65**, have insufficient pressure to meet the end use flow requirements. A check valve **26** may be positioned downstream of the pressure regulator **24** and upstream of the junction **70** to prevent backflow into the

backup liquid supply line **25**. The fifth pressure P_5 is set to a pressure from about 100 PSIG to about 140 PSIG, and is preferably about 120 PSIG.

An outlet supply line **75** is connected to the junction **70** and includes a point-of-use pressure regulator **74** to reduce the pressure of the gas to an end use pressure P_u suitable for end use. The end use pressure P_u is less than the fifth (backup liquid supply) pressure P_5 . The end use pressure is set to a pressure from about 25 PSIG to about 100 PSIG, and is preferably about 65 PSIG.

In sum, the relationship between the pressure setpoints described above in the system **100** is as follows: (a) $P_1 \geq P_m \approx P_b$, (b) $P_1 > P_3 \geq P_2$, (c) $P_1 \geq P_6 > P_2$, and (d) $P_6 \geq P_3 > P_4 > P_5 > P_u$.

The system **100** may further include a low level switch **22** in the backup tank **20** to alert an operator than the supply of cryogenic fluid is running low. Because of the relative pressure settings of the pressure regulators **54**, **64**, and **34**, the main tank **50** will drain before the backup tank **20**, so that alarming the level on the backup tank **20** provides the most accurate indication that the main tank **50** needs to be replaced or refilled. An advantage of the system **100** is that only one tank level alarm is required, on the backup tank **20**, regardless the number of main tanks **20** that are included in the system **100**.

The system **100** may further include a heat exchanger **52** in gas supply line **55** downstream of the junction **26** and upstream of the gas supply line pressure regulator **54** to warm the cryogenic gas to a temperature suitable for end use.

Note that the pressure regulators described herein may be either locally or remotely set. For example, common locally set pressure regulators are of a mechanical design that allows the output pressure to be set by a spring-loaded knob adjusting a diaphragm. Alternatively, common remotely set pressure regulators may include either a pneumatic diaphragm arrangement or an electric servo arrangement that receives a signal from a controller and/or an transducer to drive the pressure regulator in a more open or more closed direction to maintain a desired output pressure.

In use, the system **100** minimizes the loss of cryogenic fluid by operating in the following sequence. First, only if the system **100** is not in use for an extended period of time will the main tank pressure P_m and/or the backup tank pressure P_b increase sufficiently by natural heat leak to necessitate venting of cryogenic gas via one or both of the vents **59** and **29**.

Next, when gas is demanded at the point of use, the system **100** draws only cryogenic gas from the main tank **50** via the gas supply line **55**, as long as the main tank **50** is generating enough cryogenic gas. Preferably, this gas is warmed by heat exchanger **52** to a temperature suitable for end use. This gas is regulated to a pressure less than or equal to the third pressure P_3 by the pressure regulator **54**. If the main tank **50** is not generating enough gas through natural heat leak, the pressure build circuit **57** operates to add heat to the main tank **40**, thereby increasing and maintaining the pressure P_m in the main tank **50**. In addition, gas may be supplied by the backup tank **20** if natural heat leak cause the backup tank pressure P_b to increase about the pressure setting P_3 of the backpressure regulator **24**.

If the end use is stopped while only gas is being drawn from the main tank **50** and/or from the backup tank **20**, the cryogen gas remaining in the gas supply line **55** will take on some heat, but far less than a liquid cryogen would take on, and very little of this heat will be returned to the main tank **50** and/or the backup tank **20**. Therefore, the resultant loss of cryogen is maintained at a very low level during such a temporary shut-down of end use demand.

Next, only if end use demand exceeds the ability of the main tank pressure build circuit **57** to maintain the main tank pressure P_m , the system **100** draws cryogenic liquid from the main tank **50** via the main liquid supply line **65** and vaporizes that liquid in the heat exchanger **62**. When the main tank pressure P_m drops, the supply pressure to the pressure regulator **54** will drop sufficiently that the pressure at the junction **70** falls below the third pressure P_3 to the fourth pressure P_4 , thereby enabling flow through the main liquid supply line **65**. Flow will continue through the main liquid supply line **65** as long as the pressure at the junction **70** remains at or below the fourth pressure P_4 , which is the output of the pressure regulator **64**.

By lessening the demand on the gas supply line **55**, the pressure build circuit **57** is typically able to restore the main tank pressure P_m sufficiently to enable the main liquid supply line flow to cease, when the main tank **50** still contains an appreciable amount of cryogenic liquid. However, when the liquid level in the main tank **50** is running low, the pressure build circuit **57** will not be able to generate sufficient pressure to return to gas-only supply, and liquid will continue to be drawn from the liquid outlet **61** as the pressure at the junction **70** remains at or below the fourth pressure P_4 .

If the end use is stopped while both gas and liquid are being drawn from the main tank **50**, some additional heat will be returned to the main tank **50** from the liquid taking on heat in the main liquid supply line **65**. However, because of the configuration of the system **100**, liquid was being drawn because the main tank pressure P_m was too low, and specifically was less than the setpoint P_2 of the pressure build circuit **57**. Therefore, any heat returned to the main tank **50**, and the resultant pressure increase in the main tank **50**, will merely restore the main tank pressure P_m to the desired range (i.e., greater than P_2 and less than P_1) and will likely result in no, or minimal, venting or loss of cryogen.

Next, only if end use demand exceeds the ability of the main tank **50** to supply enough cryogenic fluid to maintain sufficient pressure at the junction **70**, the system draws cryogenic liquid from the backup tank **20** via the backup liquid supply line **35** and vaporizes that liquid in the heat exchanger **32**. This will occur when the main tank pressure P_m drops sufficiently that the combination of the gas supply line **51** and the main liquid supply line **61** cannot meet the end use demand, and the pressure at the junction **70** falls below the fourth pressure P_4 to the fifth pressure P_5 , thereby enabling flow through the backup liquid supply line **25**. Flow will continue through the backup liquid supply line **25** as long as the pressure at the junction **70** remains at or below the fifth pressure P_5 , which is the output of the pressure regulator **24**.

As the backup tank **20** begins to run low, the pressure build circuit **27** may need to operate to maintain sufficient pressure P_b in the backup tank **20** to feed the backup liquid supply line **21**. Finally, when the level in the backup tank **20** reaches a point indicating that the tanks **20** and **50** need to be refilled, the level switch **22** alarms.

The present invention is not to be limited in scope by the specific aspects or embodiments disclosed in the examples which are intended as illustrations of a few aspects of the invention and any embodiments that are functionally equivalent are within the scope of this invention. Various modifications of the invention in addition to those shown and described herein will become apparent to those skilled in the art and are intended to fall within the scope of the appended claims.

The invention claimed is:

1. A low-loss cryogenic fluid supply system comprising:
at least one main cryogenic fluid tank, the main tank having
a gas outlet, a liquid outlet, a pressure build circuit, and
a vent, the vent being configured and set to exhaust
pressure from the main tank at a first pressure P1, the
pressure build circuit being configured to add heat to the
main tank to thereby build pressure in the main tank to a
second pressure P2 less than the first pressure P1;
a backup cryogenic fluid tank, the backup tank having a gas
outlet, a liquid outlet, a pressure build circuit, and a vent,
the vent of the backup tank being configured to exhaust
pressure from the backup tank at the first pressure P1, the
pressure build circuit of the backup tank being config-
ured to add heat to the backup tank to thereby build
pressure in the backup tank to the second pressure P2;
a gas supply line connected to the main tank gas outlet and
having a pressure regulator configured and set to supply
gas to a junction at a third pressure P3 greater than or
equal to the second pressure P2 and less than the first
pressure P1;
a main liquid supply line having a heat exchanger to vapor-
ize liquid from the main tank liquid outlet and a pressure
regulator configured and set to supply the vaporized
liquid to the junction at a fourth pressure P4 less than the
third pressure P3;
a backup liquid supply line having a heat exchanger to
vaporize liquid from the backup tank liquid outlet and a
pressure regulator configured and set to supply the
vaporized liquid of the backup tank to the junction at a
fifth pressure P5 less than the fourth pressure P4;
a backup tank backpressure regulator configured and set to
enable gas flow from the backup tank gas outlet to a point
in the gas supply line upstream of the gas supply line
pressure regulator at a sixth pressure P6 greater than the
third pressure P3 and less than the first pressure P1; and
an outlet supply line configured to flow gas from the junc-
tion and having a point-of-use pressure regulator con-
figured and set to supply gas at an end use pressure Pu
less than the fifth pressure P5.
2. The low-loss cryogenic fluid supply system of claim 1,
further comprising:
a low level switch in the backup tank.
3. The low-loss cryogenic fluid supply system of claim 1,
further comprising: a heat exchanger in the gas supply line
upstream of the gas supply line pressure regulator.
4. The low-loss cryogenic fluid supply system of claim 1,
wherein the cryogen is oxygen.
5. The low-loss cryogen fluid supply system of claim 1,
wherein the cryogen is nitrogen.

6. A low-loss cryogenic fluid supply system comprising:
at least one main cryogenic fluid tank, the main tank having
a gas outlet, a liquid outlet, a pressure build circuit, and
a vent, the vent being configured and set to exhaust
pressure from the main tank at a first pressure P1, the
pressure build circuit being configured to add heat to the
main tank to thereby build pressure in the main tank to a
second pressure P2 less than the first pressure P1;
a gas supply line connected to the main tank gas outlet and
having a pressure regulator configured and set to supply
gas to a junction at a third pressure P3 greater than or
equal to the second pressure P2 and less than the first
pressure P1;
a main liquid supply line having a heat exchanger to vapor-
ize liquid from the main tank liquid outlet and a pressure
regulator configured and set to supply the vaporized
liquid to the junction at a fourth pressure P4 less than the
third pressure P3; and
an outlet supply line configured to flow gas from the junc-
tion and having a point-of-use pressure regulator con-
figured and set to supply gas to a point of use at a use
pressure Pu less than the fourth pressure P4.
7. The low-loss cryogenic fluid supply system of claim 6,
further comprising:
a low level switch in the main tank.
8. The low-loss cryogenic fluid supply system of claim 6,
further comprising:
a backup cryogenic fluid tank, the backup tank having a gas
outlet, a liquid outlet, a pressure build circuit, and a vent,
the vent of the backup tank being configured and set to
exhaust pressure from the backup tank at the first pres-
sure P1, the pressure build circuit of the backup tank
being configured to build pressure in the backup tank to
the second pressure P2; and
a backup liquid supply line having a heat exchanger to
vaporize liquid from the backup tank liquid outlet and a
pressure regulator configured and set to supply the
vaporized liquid of the backup tank to the junction at a
fifth pressure P5 less than the fourth pressure P4.
9. The low-loss cryogenic fluid supply system of claim 8,
further comprising:
a backup tank backpressure regulator configured and set to
enable gas flow from the backup tank gas outlet to a point
in the gas supply line upstream of the gas supply line
pressure regulator at a sixth pressure P6 greater than the
third pressure P3 and less than the first pressure P1.
10. The low-loss cryogenic fluid supply system of claim 8,
further comprising:
a low level switch in the backup tank.

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